

# 1.—Preliminary investigation of the palynology of the Upper Eocene Werillup Formation, Western Australia

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## ABSTRACT

A diverse Late Eocene plant microfossil assemblage was recovered from the Werillup Formation (Plantagenet Group) in Werillup No. 17 bore near Albany. The assemblage is composed predominantly of angiosperm pollen, with minor cryptogam and gymnosperm elements.

Common species are *Nothofagidites* spp. (mainly *brassi* group), *Proteacidites* spp., *Haloragacidites harrisi*, *Malvacipollis diversus*, *Myrtaceidites* spp., *Tricolporites prolata*, *Cyathidites minor*, and podocarpaceous species.

Most species are long ranging, however, *Proteacidites concretus*, *Cupanieidites reticularis* and *Tripoporipollenites gemmatus* restrict the assemblage to the Eocene and four other species are restricted to the Early Tertiary. Dinoflagellates in the borehole confirm the Late Eocene age determined by invertebrate fossils elsewhere in the Formation.

The following species are recorded for the first time in Western Australia: *Proteacidites concretus* Harris, *P. granulatus* Cookson, *P. reticulatus* Cookson, *P. subscabratus* Couper, *Simpliceipollis scabratus* McIntyre, *Tricolporites microreticulatus* Harris, and *Tripoporipollenites gemmatus* Harris.

The assemblage from the borehole, especially *Beaupreaidites* spp., *Cupanieidites* spp., and *Myrtaceidites mesonesus*, suggests a warm and humid climate which is consistent with other palaeoclimatic and palaeomagnetic evidence.

## Introduction

A transgressive sequence of fine-grained marine and paralic sediments was deposited on the south coast of Western Australia during the Late Eocene. The sediments compose the Plantagenet Group and contain a diverse fauna and flora that has been confidently dated.

The Plantagenet Group was intersected by a bore Werillup No. 17, drilled by the Geological Survey of Western Australia near Albany, Western Australia, and the samples collected from the sequence were examined palynologically. The aim of this study was to describe and identify the species of spores and pollen in the samples and to determine the distributions and frequencies of each species.

The samples are from the lower part of the basal formation of the Plantagenet Group. They consist of silt, sand and mud, and most have an abundant microflora. The microfloral assemblage from the bore is here related to other microfloras from the Plantagenet Group and Lower Tertiary sediments elsewhere in Australia. The assemblage is also discussed in relation to the Late Eocene climate of the

south coast of Western Australia, the palaeogeography of the region, and the environment of deposition of the sediments.

## Stratigraphy of the Plantagenet Group

The stratigraphy of the Plantagenet Group was revised by Cockbain (1968) and a review of the literature is given in his paper. The Group consists of two formations: the Pallinup Siltstone and the underlying Werillup Formation, from which the samples for this study were collected. The distribution of the Group is shown in Fig. 1.

The Werillup Formation is a sequence of dark-coloured paralic siltstone, sandstone, carbonaceous claystone and lignite that has a sporadic distribution in Precambrian basement lows. The transgressive sequence includes basal conglomerates and lignites in places, deltaic and lagoonal sediments and deeper-water siltstones and claystones. Similar lignites are also found at Nornalup, Denmark and Fitzgerald River. The sequence passes up into the Pallinup Siltstone or is unconformably overlain by Quaternary sands.

The bryozoal Nanarup Limestone Member of the Werillup Formation is of restricted lateral extent and highly fossiliferous. It only occurs at Nanarup (about 18 km ENE of Albany) and has been dated by Quilty (1969) as uppermost Eocene.

The Pallinup Siltstone consists of a light-coloured siltstone and spongolite and either conformably overlies the Werillup Formation or onlaps the Precambrian basement. It is up to 60 m thick and outcrops from Walpole to 160 km east of Esperance where it passes laterally into the Toolinna Limestone of the Eucla Basin. Where terrigenous material was negligible and conditions favoured sponges, the sediment became extremely rich in sponge spicules. Lithistid sponges in the sediments indicated the depth of deposition may have been from 20 m to 200 m (de Laubenfels 1953). The same depths when applied to spongolites of similar age and type now occurring 273 m above sea level at Norseman, indicate that the Pallinup Siltstone may have been deposited in depths up to 474 m (Clarke *et al.* 1948).

## Palaeontology of the Plantagenet Group

The Werillup Formation has abundant invertebrate remains including gastropods, cephalopods, bivalves, echinoids, sponges, foraminifers and bryozoans. The foraminifers and echinoids have been used to date the sediments

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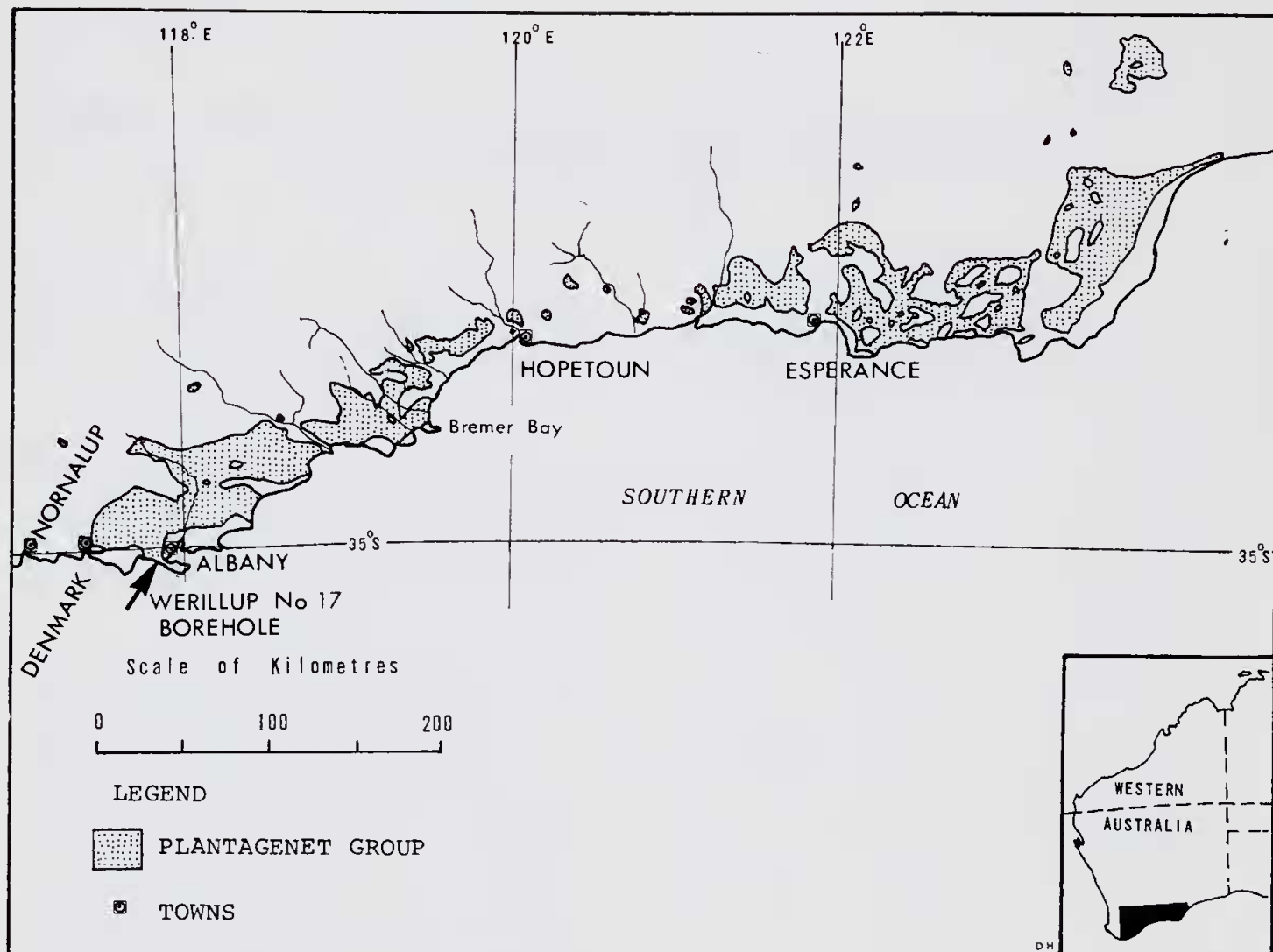


Figure 1.—Map showing location of Werillup No. 17 borehole and the distribution of the Plantagenet Group.

as Late Eocene (Quilty 1969); and *Asterocyclina* from the formation has been used as a warm-water indicator (Cockbain 1967). Cockbain (1969) recorded remains of dasycladacean algae in the Werillup Formation near Esperance which also indicated warm tropical waters.

The Kojonup Sandstone (Churchill *in* McWhae *et al.* 1958) was correlated with the Plantagenet Group and contains leaves and wood of *Nothofagus*, *Banksia* and *Araucaria*, a frond of *Gleichenia*, leaves of Moraceae, Proteaceae, a palm, and an unidentified monocotyledon.

The Pallinup Siltstone has a poorly preserved fauna of molluscs, sponges and bryozoans. Nautiloids and foraminifers are rare but both suggest a Late Eocene age (Cockbain 1968). Chapman & Crespin (1934) described leaf and wood impressions of *Agathis*, *Nothofagus* and *Bombax* from sediments considered to be part of the Pallinup Siltstone at Cape Riche (Cockbain 1968). Silicified coniferalean and proteaceous wood that is probably weathered from the Plantagenet Group is common along the south coast (Balme *in de* Jersey 1968).

Palynological work from the Lower Tertiary of Western Australia was reviewed by Balme

(*in de* Jersey 1968) and no further contributions have been published since then.

The earliest work on material from the Plantagenet Group is by Cookson (1953), who recorded *Phyllocladidites* (*Dacrydiumites*) *mawsonii* from the Group. Cookson & Pike (1953a, b, 1954a, b) recorded and described several new species from the same material. Cookson (1954b) listed all the species that had been recorded from the samples and she was able to relate the assemblage to 'Microflora C' from No. 1 Bore, Birregurra in Victoria (Cookson 1954a). The assemblage was also similar to Late Eocene microfloras from New Zealand (Couper 1953). Further records of species of *Nothofagidites* in the Plantagenet Group were given by Cookson (1954b). The assemblage reinforced plant macrofossil evidence of a pan-Australian Early Tertiary flora that had a tropical aspect (Burbidge 1960).

A Late Eocene microflora from sediments in bores and deep leads at Coolgardie was described by Balme & Churchill (1959), and on the basis of this microflora the sediments were correlated with the Plantagenet Group. The Coolgardie sediments were further examined by Churchill (1962, unpublished), who also de-

scribed the microfloras from lignites at Esperance and Norseman, and samples from Albany Bore No. 6 (near Lake Murrillup, north of the Stirling Ranges).

Upper Eocene plant microfossil assemblages from the Plantagenet Group in the Albany area were examined by Ingram (in Cockbain 1968) and similar microfloras have been found in other bores in the Albany area by the Geological Survey of Western Australia (unpublished reports).

### Material

The material on which this study is based consists of 17 sludge samples from Werillup No. 17, a water bore which is located about 9.5 km west of Albany townsite at 35°02'05"S latitude and 117°48'20"E longitude (Fig. 1). The bore was drilled by the Geological Survey of Western Australia to a depth of 61.9 m. from an elevation of about 12 m above sea level. Werillup No. 17 is one of a series of bores that are named after a nearby trigonometrical station.

Werillup No 17 was drilled by a percussion rig in 1968 and sludge samples were generally collected at 3 m intervals. The lithology of the

bore and the location of the samples down the hole is shown in Fig. 2. The top 15 m of the hole consists of Quaternary quartz aeolianite and this has not been examined palynologically.

From 16.8 m to 49.4 m the strata consist of dark coloured silts and silty sands, and from 49.4 m to 61 m of kaolinitic clay. The bottom 0.9 m of the hole was logged as weathered granite and the bore ended in granite.

Ingram (1969, unpublished report) reported Gramineae and Compositae pollen in samples from 16.8 m to 18.9 m, but these may be modern contaminants. The white clay from 49.4 m to the bottom of the hole can be interpreted as weathered granite; however, as it contains a microflora that does not differ greatly from samples higher up the bore, it is considered to be a sediment. Thus, from 16.8 m to 61 m the sediments are interpreted as belonging to the Werillup Formation.

### Palynological techniques

The technique used to macerate and concentrate the acid-insoluble microfossils was a modified hydrofluoric acid—Schultze's solution—alkali technique similar to that outlined in

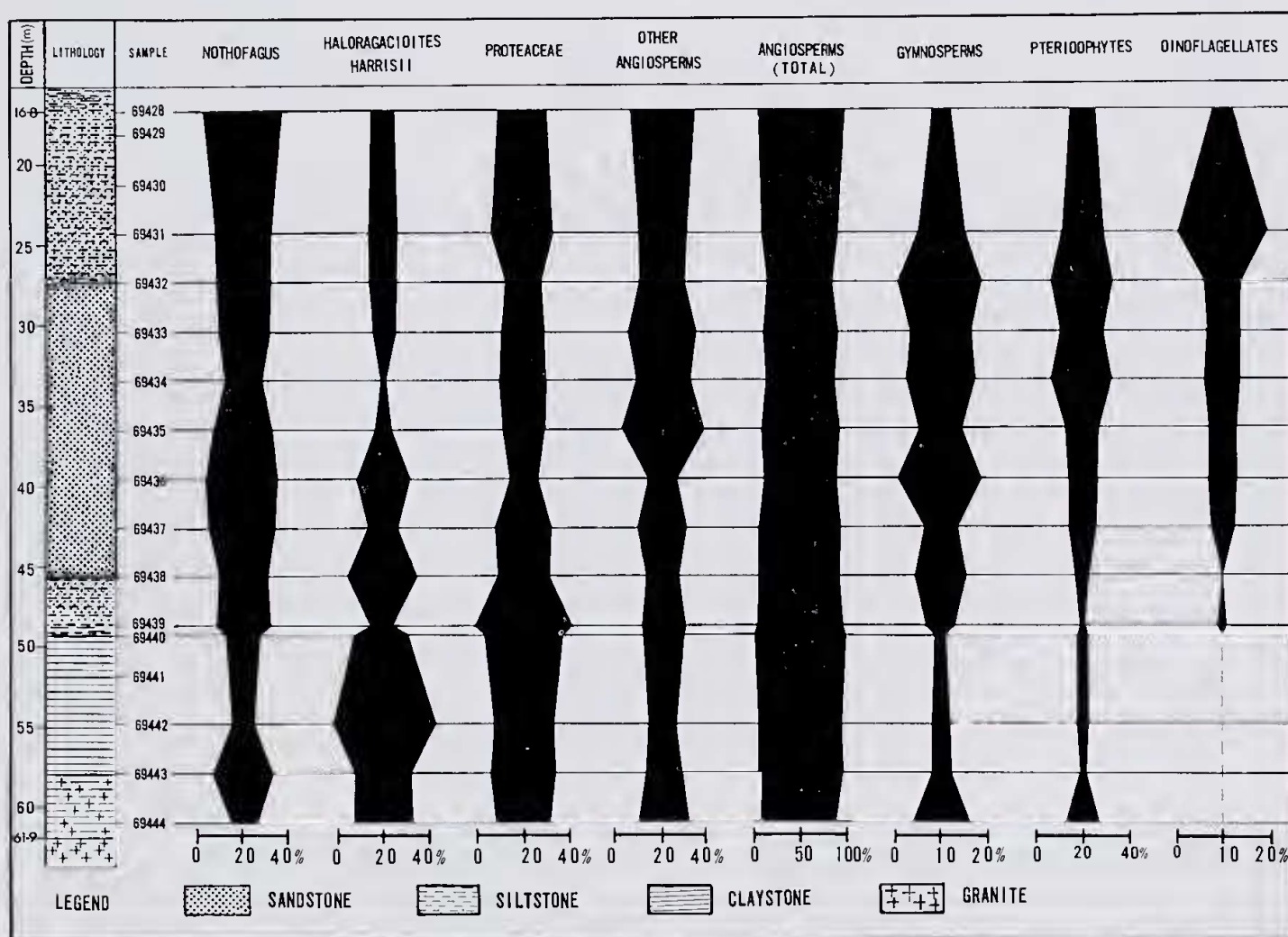


Figure 2.—Diagram showing sample depth and lithology in Werillup No. 17 borehole and the distribution of the pollen and spores of the major plant groups. The dinoflagellates are shown as a percentage of the total number of spores and pollen.

Balme & Hassell (1962). Further concentration was effected by heavy liquid separation in a zinc chloride solution of specific gravity 2.0.

Permanent strew mounts were prepared from each residue by smearing a drop of the residue on a cover slip with Clearcol (a mounting medium, H. W. Clark, Melrose, Mass., U.S.A.). The spores and pollen are able to settle in favourable orientations close to the coverslip while it is left to dry.

The cover slip was then fixed to a slide with a drop of Xam (G. T. Gurr Ltd, London). Single grain mounts of some of the species were prepared by placing the specimens in glycerine jelly under a cover slip sealed with beeswax.

The residues contained, with few exceptions, large numbers of spores, pollen and other acid-insoluble plant remains. Algal (dinoflagellate) cysts and reworked spores occurred in some samples.

Species counts were made for all except three samples which were practically barren of spores and pollen. Most samples required three or more slides to be counted to give a representative number of grains (usually about 100). The total pollen content was not determined as the samples are a sludge that may have resulted from the mixing of highly contrasting lithologies. Also, the samples may have been contaminated from higher up in the borehole (discussed below).

All samples, residues and slides used in this study are stored in collections of the Department of Geology, University of Western Australia, and all numbers given to slides and samples are from the general catalogue of the Department of Geology. The location coordinates cited in the text after the slide numbers for each specimen refer to the stage of Reichert microscope, No 256,251. A reference slide with a located point is included in the slide collection. The specimens were photographed using a Leitz Orthoplan microscope and a Leitz Orthophot camera body.

### Composition and age of the microflora

Most of the spores and pollen found in the Werillup samples can be referred to previously described species and these are listed in Table 1. However, there are some species that do not appear to have been previously described or are slightly different from existing species, and these are listed in Table 2. Unfortunately, these species are too rare to determine the significance of the differences; or to warrant detailed description at present.

The microflora in Werillup No 17 was extracted from sediments that have been previously placed in the Upper Eocene Werillup Formation (Cockbain 1968). The sediments appear to be no younger than this, as the following species (see Table 1) are restricted

Table 1

List of previously described species found in Werillup No. 17 borehole. Ranges shown are those given in the literature for the species in southern Australia and New Zealand.

SPORE-POLLEN SPECIES (ALPHABETICAL LISTING)	FIGURES	LATE CRETACEOUS	PALEOCENE	EOCENE	OLIGOCENE	MIOCENE	PLIOCENE	QUATERNARY	SPORE-POLLEN SPECIES (STRATIGRAPHICAL LISTING)
26. <i>Bankseaidites minimus</i>	27	1							<i>C. clavus</i>
36. <i>Beaupreaidites elegansiformis</i>	3	2							<i>Cycadopites</i> sp.
12. <i>Cicatricosisporites pseudotripartitus</i>	12	3							<i>L. ovatus</i>
1. <i>Cingutrilletes clavus</i>	4	4							<i>L. austroclavatus</i>
27. <i>Cupanicidites orthoichus</i>	28	5							<i>M. antarcticus</i>
40. <i>C. reticularis</i>	17	6							<i>P. ellipticus</i>
9. <i>Cyathidites minor</i>	13	7							<i>P. microreticuloidatus</i>
2. <i>Cycadopites</i> sp.	5	8							<i>P. mawsonii</i>
22. <i>Dacrycarpites australiensis</i>	29	9							<i>C. minor</i>
21. <i>Dacrydiumites florinii</i>	30	10							<i>L. variegatus</i>
14. <i>Dilwinites granulatus</i>	31	11							<i>P. parvus</i>
24. <i>D. tuberculatus</i>	32	12							<i>C. pseudotripartitus</i>
19. <i>Haloragacidites harrisii</i>	33&34	13							<i>N. (brassi group)</i>
3. <i>Laevigatosporites ovatus</i>	6	14							<i>D. granulatus</i>
10. <i>Liliacidites variegatus</i>	7	15							<i>P. granulatus</i>
4. <i>Lycopodiumsporites austroclavatus</i>	8	16							<i>P. annularis</i>
23. <i>Malvacipollis diversus</i>	35	17							<i>P. adenanthoides</i>
5. <i>Microcachrydites antarcticus</i>	14	18							<i>P. incurvatus</i>
20. <i>Myrtaceidites eucalyptoides</i>	36	19							<i>H. harrisii</i>
32. <i>M. mesonesus</i>	37	20							<i>M. eucalyptoides</i>
33. <i>M. parvus</i>	38	21							<i>D. florinii</i>
13. <i>Nothofagidites</i> sp. (brassi group)	9	22							<i>D. australiensis</i>
34. <i>N. sp. (fusca group)</i>	18	23							<i>M. diversus</i>
8. <i>Phyllocladidites mawsonii</i>	10	24							<i>D. tuberculatus</i>
6. <i>Podocarpidites ellipticus</i>	15	25							<i>T. psilatus</i>
7. <i>P. microreticuloidatus</i>	16	26							<i>B. minimus</i>
35. <i>Polycopites esobaltus</i>	39	27							<i>C. orthoichus</i>
17. <i>Proteacidites adenanthoides</i>	40	28							<i>P. pachypolus</i>
16. <i>P. annularis</i>	41	29							<i>T. microreticulatus</i>
38. <i>P. concretus</i>	19	30							<i>P. subscabratus</i>
15. <i>P. granulatus</i>	20	31							<i>T. prolata</i>
18. <i>P. incurvatus</i>	42	32							<i>M. mesonesus</i>
28. <i>P. pachypolus</i>	21	33							<i>M. parvus</i>
11. <i>P. parvus</i>	11	34							<i>N. (fusca group)</i>
39. <i>P. reticulatus</i>	43	35							<i>P. esobaltus</i>
30. <i>P. subscabratus</i>	22	36							<i>B. elegansiformis</i>
37. <i>Simplicipollis scabratus</i>	23	37							<i>S. scabratus</i>
29. <i>Tricolporites microreticulatus</i>	24	38							<i>P. concretus</i>
31. <i>T. prolata</i>	25	39							<i>P. reticulatus</i>
25. <i>'Triorites' psilatus</i>	44	40							<i>C. reticularis</i>
41. <i>Triporopollenites gemmatus</i>	26	41							<i>T. gemmatus</i>

**Table 2**

List of species found in Werillup No. 17 borehole that do not appear to have been previously described, or which could not be assigned with confidence to existing species due to their very rare occurrence.

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<i>Bombacacidites</i> sp., fig. 45, rare
<i>Ceratospores</i> sp. cf. <i>C. equalis</i> Cookson & Dettmann, fig. 46, rare
<i>Clavatipollenites</i> sp. cf. <i>C. ascarinoides</i> McIntyre, fig. 47, rare
<i>Liliacidites</i> sp. cf. <i>L. aviemorensis</i> McIntyre, fig. 48, rare
<i>Liliacidites</i> sp., fig. 49, common
<i>Monosulcites</i> spp., figs 50 and 51, rare
<i>Polypodioidites</i> sp., fig. 52, rare
<i>Polyporina</i> sp., fig. 53, common
<i>Proteacidites</i> sp. cf. <i>P. annularis</i> Cookson, fig. 54, common
<i>Proteacidites</i> sp. cf. <i>P. crassus</i> Cookson, fig. 55, rare
<i>Proteacidites</i> sp. cf. <i>P. minimus</i> Couper, fig. 56, rare
<i>Proteacidites</i> sp. cf. <i>P. parvus</i> Cookson, fig. 57, rare
<i>Proteacidites</i> sp. 1, fig. 58, common
<i>Proteacidites</i> sp. 2, fig. 59, rare
<i>Proteacidites</i> sp. 3, fig. 60, rare
<i>Proteacidites</i> spp., figs 61 to 68, abundant
<i>Retitricolporites</i> sp., fig. 69, rare
<i>Tricolpites</i> sp. cf. <i>T. aspermarginis</i> McIntyre, fig. 70, rare
<i>Tricolpites</i> sp. cf. <i>T. lilliei</i> Couper, fig. 71, rare
<i>Tricolpites</i> sp. cf. <i>T. matauraensis</i> Couper, fig. 72, rare
<i>Tricolpites</i> sp. cf. <i>T. pachyexinous</i> Couper, fig. 73, rare
<i>Tricolpites</i> sp., fig. 74, rare
<i>Tricolporites</i> spp., figs 75 and 76, rare
' <i>Triorites</i> ' sp. cf. <i>T. minisculis</i> McIntyre, fig. 77, common
' <i>Triorites</i> ' sp. cf. <i>T. minor</i> Couper, fig. 78, rare
' <i>Triorites</i> ' sp. cf. <i>T. orbiculatus</i> McIntyre, fig. 79, rare
' <i>Triorites</i> ' spp., figs 80 and 81, rare

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to the Eocene: *Proteacidites concretus*, *P. reticulatus*, *Cupanieidites reticularis* (described from two localities in Victoria) and *Triporopollenites gemmatus*. Also, the Nanarup Limestone Member, which is stratigraphically higher than the Werillup No 17 sequence is no younger than uppermost Eocene (Quilty 1969).

The age of the base of the Werillup Formation has not been determined precisely and whether it extends into Middle Eocene cannot be resolved satisfactorily with the present data. The species identified as *Proteacidites incurvatus* and "*Triorites*" *psilatus* require further study before their chronostratigraphic significance can be fully assessed. *Triporopollenites gemmatus* is the only species useful in placing a lower limit on the age of the microflora as it is known only from Middle and middle-Upper Eocene strata in South Australia and the Great Artesian Basin (Harris 1972). Some of the dinoflagellates in the samples, e.g. species of *Wetzeliella* (figure 82) and *Cordosphaeridium* (figure 83), support the assignment of the sediments to the Upper Eocene (Dr. B. E. Balme 1972, personal communication).

Several specimens of reworked spores were encountered in the uppermost samples (figures 84, 85 and 86) and they have been identified by Dr. B. E. Balme as characteristic Lower Cretaceous forms. Lower Cretaceous sediments are found in the Eucla Basin (Ingram 1968) and in the southern Perth Basin (Lowry 1965). However these are too far away to be considered as possible sources.

There may have been pockets of Lower Cretaceous sediments nearby that were eroded during the transgression and have since been covered up or completely removed.

#### Comparison of the microflora with other assemblages

The microfloral assemblage from Werillup No 17 is similar to Late Eocene microfloras previously described from southern Australia and New Zealand. Differences between the Werillup microflora and other assemblages from sediments correlated with the Plantagenet Group by Cookson (1954b), Balme & Churchill (1959) and Churchill (1962, unpublished) have no stratigraphical significance as the species are long ranging. They may have a phytogeographical significance, but there are insufficient data on which to base evaluations.

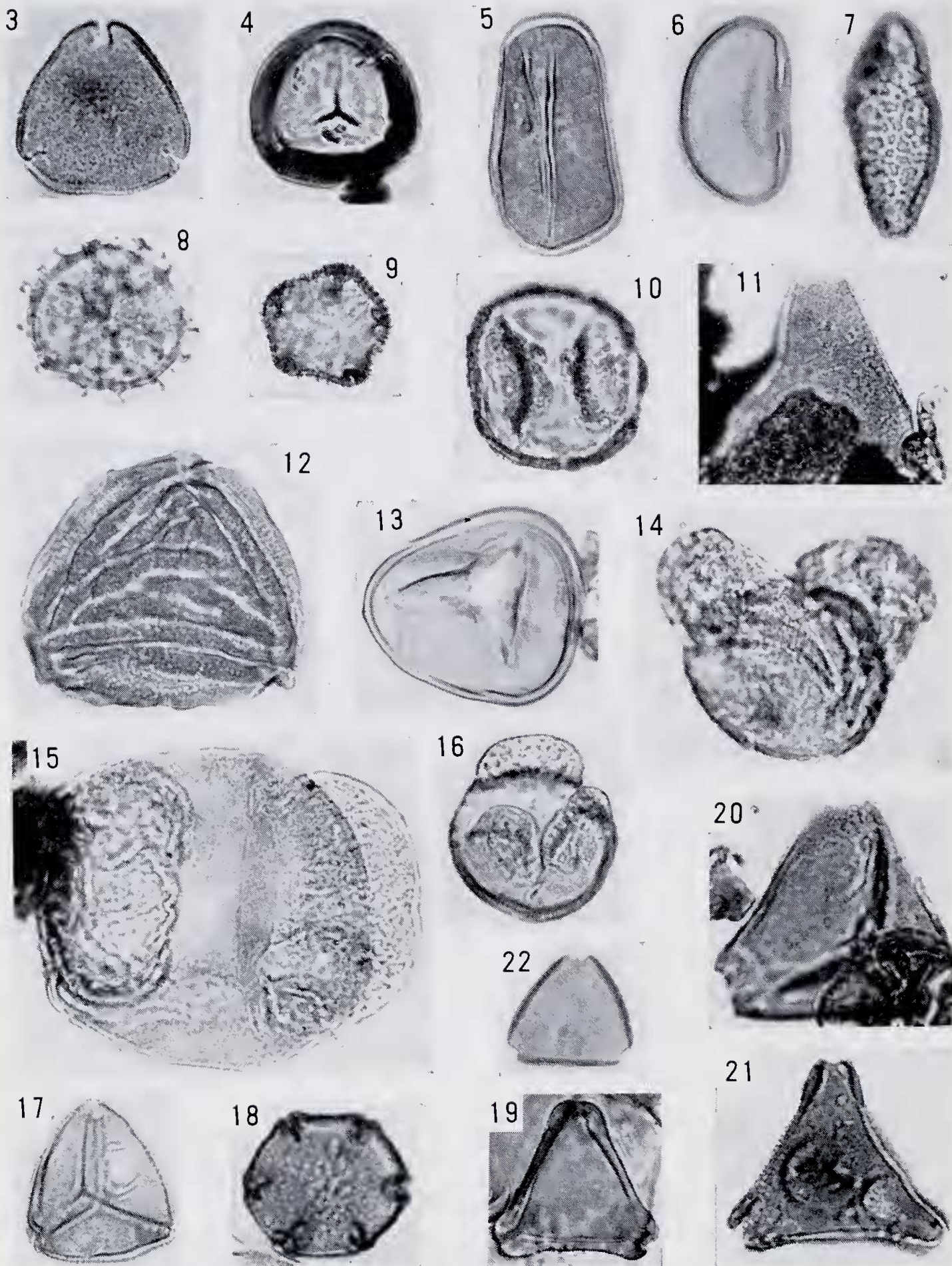
Cookson (1954b) correlated the microflora from the Plantagenet Group with Microflora C from Victoria, mainly on the basis of *Proteacidites pachypolus*, which is now known to be long-ranging. Harris (1971) related Microflora C to the *Triorites magnificus* Zonule of the Otway Basin (Middle to Late Eocene). There are only 5 species from the Werillup microflora that are common with the *T. magnificus* Zonule, but they are of limited stratigraphical value as they also occur in the uppermost Palaeocene *Cupanieidites orthoteichus* Zonule.

Correlations with the other palynological zonules of Harris (1971) are also not possible. The Upper Eocene "*Aglaoreida barungensis*" (Harris, unpublished) Zonule could not be recognized as it does not have any characteristic species that are present in the Werillup borehole. The Werillup microflora contains at least 14 species that are present in the informal Oligocene *Verrucatosporites* Zonule in the Otway Basin.

Most of the species in the microflora are found in the Early Tertiary Unit 1 set up by Hekel (1972) and in the Late Eocene microfloras of New Zealand (Couper 1960, Wilson 1968). However, the species only allow a broad correlation. McQueen *et al.* (1968) note that from the Kaiatan to Runangan there is an abrupt change from the *Nothofagus fusca* group to a dominance of the *Nothofagus brassi* group. The latter group is similarly dominant in the Werillup microflora and it is the same age as part of the Runangan Stage of New Zealand. The apparent uniformity of the microfloras throughout southern Australia and New Zealand during the Late Eocene suggests that the climate over the region was very uniform.

#### Palaeoecology of the microflora

The palaeoecological interpretation of a microflora depends on the reliability with which the spores and pollen can be related to modern plants. Such determinations become less reliable as older spores and pollen are examined and are usually not attempted with pre-Tertiary fossils. However, many of the species in the Werillup microflora have been related fairly



confidently to living genera and families. Most workers accept that the ecological tolerances of the plants that are represented in Early Tertiary microfloras have not altered during the Cainozoic (Burbidge 1960). The microflora as a whole will be discussed first, and then the variations within the microflora.

#### *The palaeoecology of the assemblage*

The general microfloral assemblage in the samples does not differ greatly from other assemblages described in the Plantagenet Group, and the additional species encountered do not alter the palaeoecological conclusions of previous authors. Three floristic elements have been recognized in the Lower Tertiary floras of southern Australia (Burbidge 1960). They have been called the 'Antarctic', 'Tropical' and 'Australian' elements, and the spores and pollen that belong to these groups will now be discussed.

The 'Antarctic' elements in the microflora are species of *Nothofagidites* and Podocarpaceae whose major development has been in the southern hemisphere and appear to have migrated to Australia and New Zealand from Antarctica. *Nothofagidites* is the most commonly represented pollen in the assemblage (though pollen from other plant groups is more abundant in several samples) and it is predominantly of the type that has been closely related to the pollen of species of the *Nothofagus brassi* group (Cookson & Pike 1955).

The *Nothofagus brassi* group at present grows in areas of moderate to high rainfall in New Caledonia (above 600-900 m) and in New Guinea (above 2400 m). It indicates a climate of constant humidity and one warmer than that occupied by the *N. fusca* group (McQueen *et al.* 1968). Pollen from the *brassi* group is recorded from Eocene to Pliocene in New Zealand and is abundant in Queensland from Eocene to Miocene. The *N. brassi* group is an evergreen forest dominant that requires dense forest for regeneration. It is a very heavy pollen producer and is probably over-represented in the pollen spectrum (Cranwell 1964).

Gymnosperms were probably not an important part of the vegetation as they make up only 9% of the microflora. They are mainly podocarps with extant genera now living in a wide range of climates. High proportions of *Podocarpus* pollen in a Quaternary core off Argentina was used as an indicator of cooler climates when compared with the proportions of pollen from

*Nothofagus*, Cupressaceae and *Weinmania* (Groot & Groot 1966).

*Dilwynites* has a down-hole distribution similar to the conifers and has been compared to several living conifers (for example *Callitris*), however, Harris (1965) considers an angiospermous affinity for the pollen more likely. *Dacrycarpites australiensis* was compared to the pollen of *Podocarpus* section *Dacrycarpus* which has its major development in New Guinea (Cookson and Pike 1953a). *Microcachryidites antarcticus* and *Phyllocladidites mawsonii* are common compared with the other podocarps in the assemblage, and have been related to two living podocarps, *Microcachrys tetragona* and *Dacrydium franklinii* respectively, both of which are restricted to Tasmania (Cookson 1947). These podocarps flourish under cool temperate conditions with a moderate rainfall.

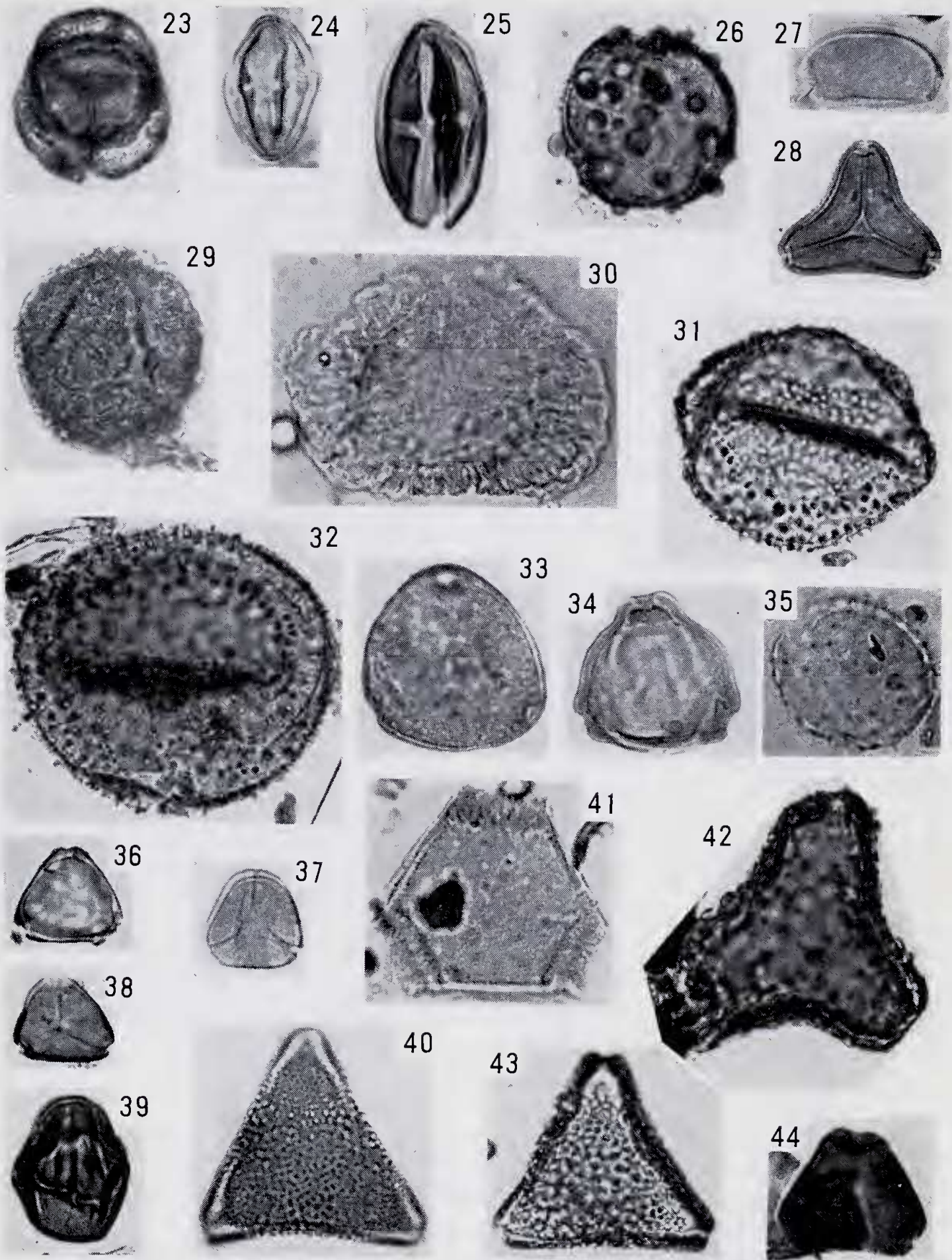
*Podocarpidites* represents pollen with general podocarpaceous affinities, and which may now be found in plants living in both tropical and temperate conditions. A similar distribution is found for a number of species of *Dacrydium*, which have the same pollen as *Dacrydiumites florinii* (Cookson and Pike 1953b).

Thus the mesophytic 'Antarctic' species of *Nothofagus* and the podocarps, which are now restricted to cool temperate and tropical submontaine regions, indicate a rainforest vegetation. The moss *Sphagnum* is represented in the assemblage by *Cingutruletes clavus* (Dettmann 1963) and indicates swampy conditions. Lycopods are represented by *Lycopodiumsporites*, and *Selaginella* by *Ceratospores* (Dettmann 1963).

Pteridophytes make up a small proportion of the assemblage and several families are present, including tree ferns. *Cyathidites minor* has been related to ferns such as Cyatheaceae and Dicksoniaceae, and *Cicatricosisporites* resembles some modern spores of *Anemia* in the family Schizeaceae (Dettmann 1963). *Laevigatosporites* and *Polypodiidites* have been compared to spores from Polypodiaceae. The pteridophytes have a broad distribution in high rainfall areas of the tropical and temperate regions and their presence in the microflora indicates conditions wetter than at present.

The "Tropical" elements in the microflora from Werillup No. 17 are species that have been related to families now distributed mainly in the tropical and subtropical regions of Australia and the Indo-Pacific. The species are *Beaupreaidites elegansiformis*, *Bombacacidites* sp., *Cupanieidites* sp., *Malvacipollis diversus* and

Figures 3 to 22.—All figures at x1000 unless otherwise stated. 3.—*Beaupreaidites elegansiformis* Cookson. Slide 69428b, 132.9 x 42.5. 4.—*Cingutruletes clavus* (Balme) Dettmann. Slide 69445. *Cycadopites* sp. Slide 69428a, 129.0 x 47.5. 6.—*Laevigatosporites ovatus* Wilson and Webster. Slide 69444a, 115.7 x 24.9. 7.—*Liliacidites variegatus* Couper. Slide 69451. 8.—*Lycopodiumsporites austroclavatidites* (Cookson) Potonié. Slide 69428b, 120.2 x 32.2. 9.—*Nothofagidites* sp. (*Nothofagus brassi* group). Slide 69486. 10.—*Phyllocladidites mawsonii* Cookson. Slide 69450. 11.—*Proteacidites parvus* Cookson. Slide 69431a, 125.9 x 43.7. 12.—*Cicatricosisporites pseudotripertitus* (Bolkhovtina) Dettmann. Slide 69428b, 123.2 x 32.2. 13.—*Cyathidites minor* Couper. Slide 69428b, 123.9 x 35.0. 14.—*Microcachryidites antarcticus* Cookson. Slide 69428b, 128.9 x 28.8. 15.—*Podocarpidites ellipticus* Cookson. Slide 69428b, 133.8 x 45.6. 16.—*Podocarpidites microreticuloidatus* Cookson. Slide 69428a, 113.1 x 37.4. 17.—*Cupanieidites reticularis* Cookson and Pike. Slide 69428b, 125.2 x 35.7. 18.—*Nothofagidites* sp. (*Nothofagus fusca* group). Slide 69438b, 131.4 x 39.5. 19.—*Proteacidites concretus* Harris. Slide 69428b, 136.3 x 25.8. 20.—*Proteacidites granulatus* Cookson. Slide 69428b, 132.7 x 25.8. 21.—*Proteacidites pachypolus* Cookson and Pike. Slide 69428b, 134.2 x 35.4. 22.—*Proteacidites subscabratus* Couper. Slide 69428b, 135.6 x 38.5.





*Myrtacidites mesonesus*. Additional "Tropical" species previously described from the Plantagenet Group but not found in the present study are *Anacolosidites* sp., "*Palmidites*" sp. and "*Santalumidites cainozoicus*".

*Beaupreaidites* has been related to the pollen of *Beauprea* (Proteaceae) which occurs in New Caledonia and New Guinea (Cookson 1950). The determination of *Bombacacidites* sp. is not reliable, however, the pollen is common in the Eocene of New Zealand (Couper 1960). Leaves of *Bombax* (kapok tree) are recorded from the Plantagenet Group at Cape Riche (Chapman and Cressin 1934), thus there is evidence that the tropical species was present on the south coast of Western Australia during the Eocene.

The two species of *Cupanieidites* in the Werillup microflora have been compared to the pollen from Sapindaceae tribe Cupanieae, which is a component of tropical and south-eastern Australian rainforests (Cookson and Pike 1954b). The family Malvaceae has its major distribution in the tropics at present, and is represented in the microflora by *Malvacipollis diversus*. *Myrtacidites mesonesus* has been related to a species of *Whiteodendron* now living in Indonesia (McWhae 1957).

*Anacolosidites* is from the family Olacaceae in which the genera are now restricted to the tropics. It was pan-tropical from Palaeocene to Eocene, and was common in Borneo and Queensland throughout the Tertiary (Germeraad *et al.* 1968, Hekel 1972). "*Santalumidites cainozoicus*" is considered (in part) a synonym of *Florschuetzia levipoli* (Germeraad *et al.* 1968). This species is similar to the pollen of *Sonneratia caseolaris*, a mangrove at present growing in estuaries along the Indo-Malesian coasts. The form genus '*Palmidites*' is of uncertain reliability, however, palm pollen is recorded from the Upper Eocene of New Zealand, and supports the evidence for warmth (McQueen *et al.* 1968).

The above 'Tropical' species indicate that the Late Eocene climate on the south coast was sub-tropical or warmer. These 'Tropical' species are also represented elsewhere in the Late Eocene of southern Australia, and in New Zealand (Harris 1971, Couper 1960), and suggest that the Australasian region was characterised by a warm and humid climate during this period.

The 'Australian' elements in the microflora are species such as *Myrtacidites eucalyptoides*, *Haloragacidites harrisii*, *Banksiaeidites* and *Proteacidites*. *Banksiaeidites* is similar to the

pollen found in *Banksia* and *Dryandra* (Cookson 1950). *Proteacidites adenanthoides* has been compared to the pollen of *Adenanthos* and *P. annularis* has been related to the pollen of *Xylomelum occidentale*, a tree occurring in the Jarrah forest of the south-west of Western Australia (Cookson 1950).

Other species of *Proteacidites* found in the Plantagenet Group by previous workers include *P. rectomarginis*, which has a possible affinity to *Petrophile*, and *Proteacidites symphyonemoides*, related to *Symphyonema* (Cookson 1950).

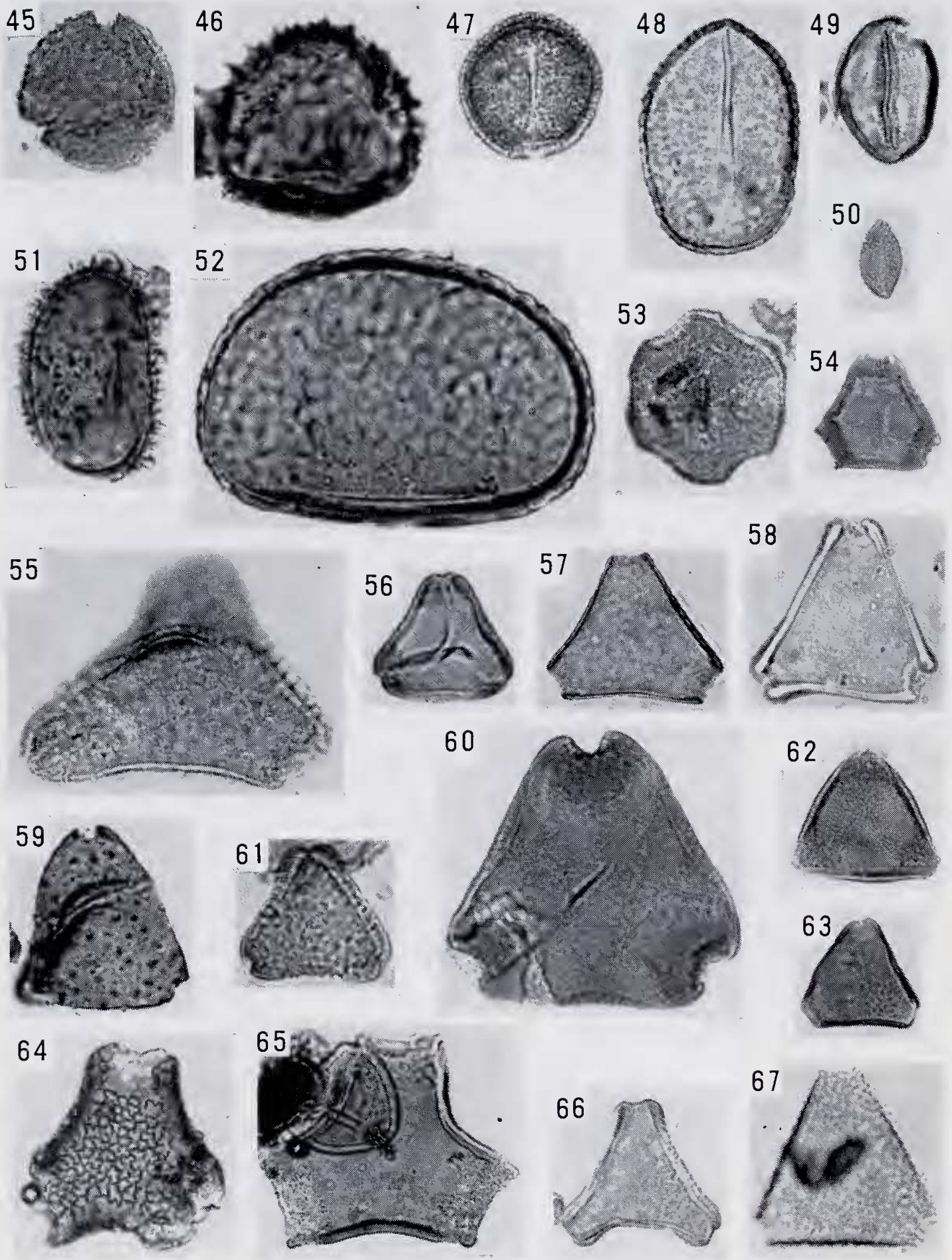
The family Proteaceae diversified in the Late Cretaceous and possibly originated in the rain-forest environment of south-eastern Australia and South-West Pacific (Muller 1970). The Werillup microflora includes over 30 proteaceous species and these compose up to 24% of the total microflora. Proteaceous pollen is the most abundant pollen type in several samples, and it is more abundant towards the bottom of the borehole. The wide diversity and abundance of proteaceous pollen suggest that Proteaceae were a major constituent of the vegetation and that the climate was warmer than cool temperate.

The form species *Haloragacidites harrisii* principally represents pollen from *Casuarina*, though other plants with similar pollen were probably present in the vegetation. The form species composes up to 16% of the total microflora and it is considerably more abundant in some samples. The less markedly aspidate pollen grains placed in the form species have been related to pollen from Haloragaceae and genera such as *Geniostoma* and *Canacomyrca*. These are now living mainly in the tropics (Mildenhall & Harris 1971).

The broad palaeovegetative pattern gained from the spores and pollen is that of a tropical to subtropical rainforest (closed-forest). The predominance of tree pollen relative to the proportion of non-tree pollen is indicative of a rainforest (Churchill 1962, unpublished). The subtropical vegetation suggests a climate considerably warmer and more humid than the present climate along the south coast of Western Australia, which is mild, cool temperate, with a warm to hot dry summer.

The southern beeches (*Nothofagus*) appear to have been forest dominants, with Proteaceae and *Casuarina* as subdominants. Other elements of the forest were podocarpaceous conifers, pteridophytes and the 'Tropical' species.

Figures 23 to 44.—All figures at x1000 unless otherwise stated. 23.—*Simplicipollis scabratus* McIntyre. Slide 69473. 24.—*Tricolporites microreticulatus* Harris. Slide 69439a, 123.1 x 31.2. 25.—*Tricolporites prolata* Cookson. Slide 69428b, 132 x 40.7. 26.—*Tripoporollenites gemmatus* Harris. Slide 69428d, 119.0 x 44.1 (single grain). 27.—*Banksiaeidites minimus* Cookson. Slide 69439a, 127.0 x 26.4. 28.—*Cupanieidites orthoteichus* Cookson and Pike. Slide 69428a, 121.7 x 50.7. 29.—*Dacrycarpites australiensis* Cookson and Pike. Slide 69428b, 125.8 x 30.2. 30.—*Dacrydiumites florinii* Cookson and Pike. Slide 69449. 31.—*Dilwynites granulatus* Harris. Slide 69447. 32.—*Dilwynites tuberculatus* Harris. Slide 69448. 33, 34.—*Haloragacidites harrisii* (Couper) Harris. Fig. 33, slide 69453. Fig. 34, slide 69428a, 129.8 x 27.2. 35.—*Malvacipollis diversus* Harris. Slide 69439a, 123.7 x 48.1. 36.—*Myrtacidites eucalyptoides* Cookson and Pike. Slide 69471. 37.—*Myrtacidites mesonesus* Cookson and Pike. Slide 69428b, 121.5 x 49.3. 38.—*Myrtacidites parvus* Cookson and Pike. Slide 69472. 39.—*Polycopites esobalteus* McIntyre. Slide 69428b, 132.7 x 32.8. 40.—*Proteacidites adenanthoides* Cookson. Slide 69444a, 115.7 x 24.9. 41.—*Proteacidites annularis* Cookson. Slide 69439a, 133.5 x 39.3. 42.—*Proteacidites incurvatus* Cookson. Slide 69431b, 121.3 x 29.5. 43.—*Proteacidites reticulatus* Cookson. Slide 69457. 44.—"*Triorites*" *psilatus* Harris. Slide 69428a, 121.8 x 45.5.



The diverse 'Australian' element, especially the Proteaceae, is now characteristic of a climate with a marked dry season. It is difficult to explain the presence of this element in a vegetation growing in humid conditions and that includes *Nothofagus*, which cannot withstand long periods of dry conditions.

A Middle Eocene flora from Maslin Bay, South Australia includes *Araucaria*, *Casuarina* and Proteaceae, and a leaf macroflora which has a broad similarity to some leaf litters from present day Queensland wet forests (Lange 1970). Thus, it is possible that the Early Tertiary rain-forest vegetation on the south coast included a high proportion of Proteaceae. An alternative interpretation is that the "Australian" element represents species from a flora further inland in a drier and more seasonal climate.

#### *Analysis of down-hole variations in the microflora*

Palaeoecological interpretations from palynological data are subject to many reservations, and when based on the results from one bore-hole, must be regarded with even more caution. The importance of the relative pollen production of the plants and the hydrodynamic properties of the grains have been stressed; yet there is very little quantitative information on these parameters (Davis 1963, Brush & Brush 1972). Additional cause for concern is the possibility of sampling errors during drilling.

Differential effects resulting from processing techniques were probably minimal, as were errors due to counting techniques and identifying the species. Most of the spores and pollen in the samples were well-preserved and contamination with modern pollen was negligible.

The number of counts per sample though not ideal was probably representative. The total number of spores and pollen in each sample was selected as the pollen sum. This is probably not justified ecologically, and it can be seen that the angiosperms are over-represented (Fig. 2). Thus, changes in the frequencies of the pteridophytes or gymnosperms will be masked to some extent. However, the total pollen sum is the most commonly used, and the easiest to interpret.

The down-hole distribution of the major plant groups is shown in Fig. 2. There appear to be several horizons with simultaneous changes in the groups. However, three of these horizons represented by samples 69443, 69439 and 69432 coincided with lithological changes, and this is almost certainly significant. Brush & Brush

(1972) found that pollen frequencies were dependent on distance from source and lithology. However, Cross & Shaeffer (1965) concluded that pollen frequencies in surface sediments of the Gulf of California were independent of sediment types, except where these were coarse.

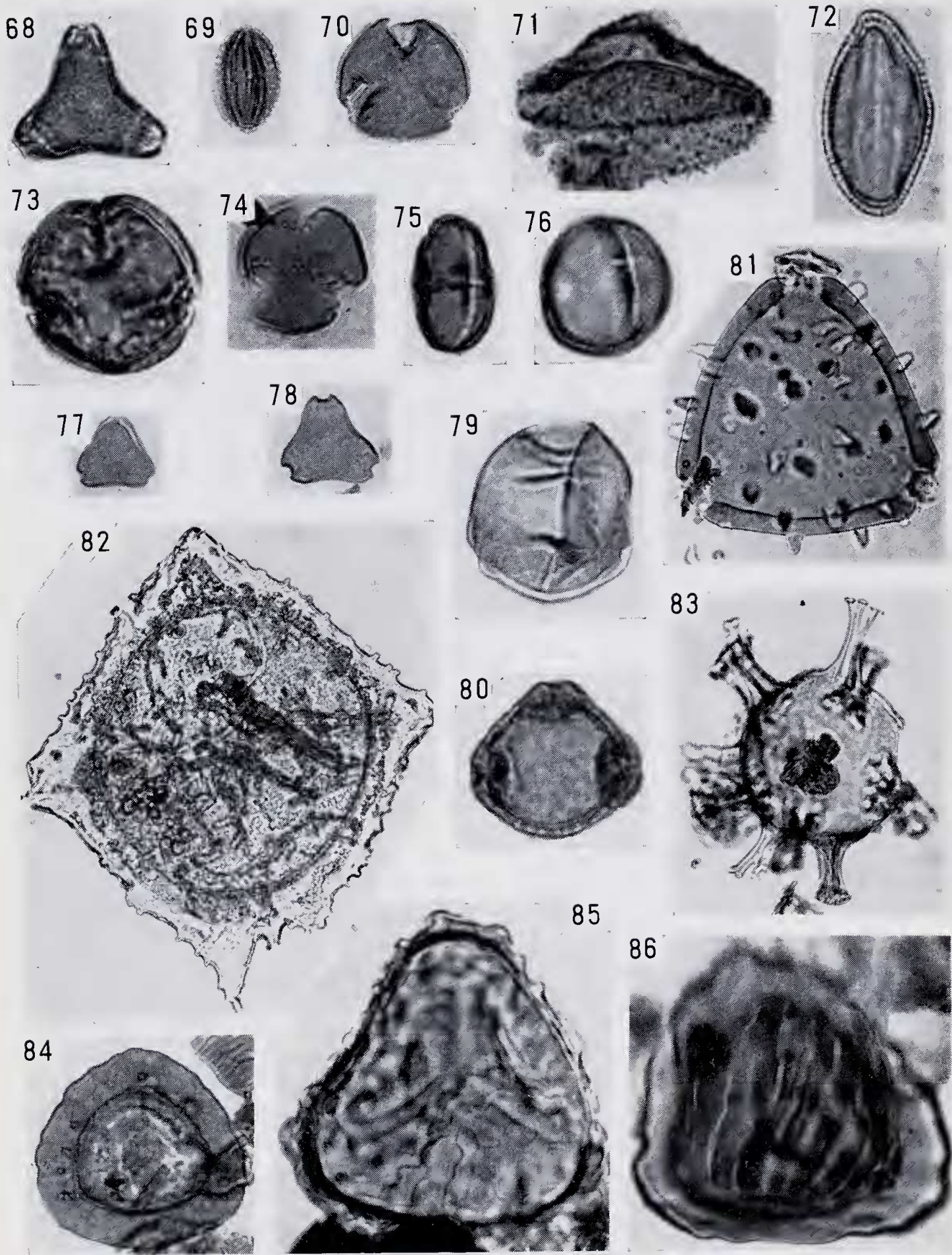
Contamination during sampling is unpredictable but could be expected to occur, as the samples are a sludge from poorly consolidated sediments. It was indicated above that samples 69443 and 69444 were logged as weathered granite. However, they appear to contain a microflora similar to the samples stratigraphically higher, and this may be the result of contamination due to caving higher up. It is not possible to determine from the lithology of the samples whether they are detrital or the result of *in situ* weathering of the underlying granite and it was accepted that the pollen frequencies obtained from the samples were reliable. However, down-hole contamination may have occurred continuously during drilling and cannot be neglected. It may be the reason for the general uniformity of the frequencies down the hole and thus any interpretation of the pollen diagram must be regarded with caution.

The sediments from the bore can be interpreted as a standard transgressive sequence of paralic sediments grading into deeper-water facies. At Sample 69438, there is a change from clays and silts to a sand that becomes progressively finer upwards, until it is a clayey silt at the top. This suggests an increasingly deeper-water environment and the presence of dinoflagellates (Fig. 2) indicates that the upper sediments are marine.

If the sediments were being deposited in water that was becoming deeper with time, a change in the frequencies of the spores and pollen could be expected with increasing distance from the shoreline. Such a trend could not be differentiated from changes in the contributing vegetation resulting from changes in the climate. Local topography may also have influenced spore and pollen frequencies. There are nearby hills up to 150-180 m high that were probably vegetated during early stages of the transgression. These may have contributed spores and pollen to the sediments. Little can be said of Early Tertiary relief elsewhere on the south coast, but it was probably not high enough to affect vegetational patterns in any pronounced way.

The problems of contamination, increasing distance from the shoreline and changes in

Figures 45 to 67.—All figures at x1000 unless otherwise stated. 45.—*Bombacacidites* sp. Slide 69428b, 126.5 x 40.0. 46.—*Ceratospores* sp. cf. *C. equalis* Cookson and Dettmann. Slide 69431a, 123.3 x 47.2. 47.—*Clavatiipollenites* sp. cf. *C. ascarinoides* McIntyre. Slide 69467. 48.—*Liliacidites* sp. cf. *L. aviemorensis* McIntyre. Slide 69428a, 125.2 x 39.2. 49.—*Liliacidites* sp. Slide 69428b, 124.8 x 28.2. 50, 51.—*Monosulcites* spp. Fig. 50, slide 69428b, 132.8 x 34.9. Fig. 51, slide 69428a, 135.0 x 34.6. 52.—*Polyodiidites* sp. Slide 69442a, 132.0 x 39.5. 53.—*Polyporina* sp. Slide 69428b, 130.7 x 35.9. 54.—*Proteacidites* sp. cf. *P. annularis* Cookson. Slide 69454. 55.—*Proteacidites* sp. cf. *P. crassus* Cookson. Slide 69444a, 118.3 x 27.4. 56.—*Proteacidites* sp. cf. *P. minimus* Couper. Slide 69428b, 132.8 x 29.2. 57.—*Proteacidites* sp. cf. *P. parvus* Cookson. Slide 69432a, 125.7 x 34.7. 58.—*Proteacidites* sp. 1. Slide 69458. 59.—*Proteacidites* sp. 2. Slide 69428a, 127.9 x 44.3. 60.—*Proteacidites* sp. 3. Slide 69428b, 134.2 x 41.7. 61 to 67.—*Proteacidites* spp. Fig. 61, slide 69428a, 127.0 x 26.5. Fig. 62, slide 69543a, 128.4 x 39.1. Fig. 63, slide 69459. Fig. 64, slide 69460, x 540. Fig. 65, slide 69456, x 540. Fig. 66, slide 69428a, 121.1 x 25.7. Fig. 67, slide 69465.



lithology make detailed inferences concerning changes in the vegetation with time impossible. However, several broad trends in Fig. 2 may be significant.

The proportions of pteridophytes, gymnosperms and *Nothofagus* are slightly greater in the marine section above sample No. 69440 and this may reflect either cooler conditions or increased humidity. The marine section, as noted above, appears to have been deposited in deeper water, which implies that a greater area of the southern shield was covered by the shallow sea. Topographical highs, however, would remain as islands and form an archipelago with a much higher humidity and rainfall. If part of the contributing vegetation was growing on the islands and low-lying areas near the shallow sea, it may explain the trend shown by the spores and pollen. A general reduction in the temperature of southern Australia began at the end of the Eocene (Dorman 1968), but whether this is also reflected in the samples cannot be stated.

The palaeolatitude of the south coast of Western Australia during the Late Eocene was higher than 41°S and possibly as high as 60°S (Le Pichon & Heirtzler 1968, Wellman *et al.* 1969). That the subtropical vegetation represented by the Werillup microflora was able to flourish on the south coast at such a high latitude indicates that the climate during the Late Eocene was considerably warmer than at present.

Tropical dasycladacean algae and the warm-water foraminifer *Asterocyclina* present in the Plantagenet Group (Cockbain, 1967, 1969) indicate that the Southern Ocean was warmer during the Late Eocene. This is supported by oxygen isotope data from south-eastern Australia and New Zealand (Dorman 1968, Devereux 1967).

The warmer temperatures agree with worldwide palaeoclimatic data from the Eocene reviewed by Frakes & Kemp (1972). They used oxygen isotope palaeotemperatures that had been determined from the Middle Eocene of New Zealand to infer that even at a latitude of 60°S the temperature of ocean surface water probably exceeded 15°C.

The warmer oceans would have a high evaporation rate, producing high humidity and rainfall on the south coast of Western Australia. The warm, shallow transgressive sea would also have modified the coastal region, reducing the influence of cooler winter temperatures. An inland vegetation in a drier and more seasonal climate is also possible.

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Figures 68 to 86.—All figures at x1000 unless otherwise stated. 68.—*Proteacidites* sp. Slide 69462. 69.—*Retitricolporites* sp. Slide 69428a, 128.0 x 25.0. 70.—*Tricolpites* sp. cf. *T. aspermarginis* McIntyre. Slide 69428b, 122.4 x 38.2. 71.—*Tricolpites* sp. cf. *T. lilliei* Couper. Slide 69428b, 134.1 x 47.5. 72.—*Tricolpites* sp. cf. *T. matauraensis* Couper. Slide 69474. 73.—*Tricolpites* sp. cf. *T. pachyexinous* Couper. Slide 96444a, 137.3 x 36.1. 74.—*Tricolpites* sp. Slide 69428b, 130.5 x 42.4. 75, 76.—*Tricolporites* spp. Fig. 75, slide 69475. Fig. 76, slide 69476. 77.—*Triorites* sp. cf. *T. minisculis* McIntyre. Slide 69428b, 134.7 x 20.2. 78.—*Triorites* sp. cf. *T. minor* Couper. Slide 69428a, 126.0 x 49.6. 79.—*Triorites* sp. cf. *T. orbiculatus* McIntyre. Slide 69428b, 131.5 x 30.4. 80, 81.—*Triorites* sp. Fig. 80, slide 69479. Fig. 81, slide 69451, x 540. 82.—*Wetzeliella* sp. Slide 69488, x 540. 83.—*Cordosphaeridium* sp. Slide 69428c, 130.9 x 45.8, x 540. 84.—*Cingulatisporites saevus* Balme. Slide 69428a, 135.3 x 43.7. 86.—*Contignisporites glebulentus* Dettmann. Aptian to Albanian. Slide 69428c, 135.3 x 30.0. 85.—*Klukisporites* sp. cf. *K. pseudoreticulatus* Couper. Late Jurassic to Early Cretaceous. Slide 69428a, 125.7 x 30.0

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